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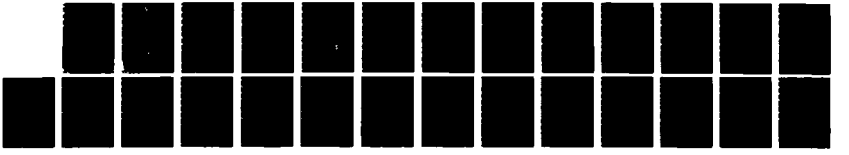

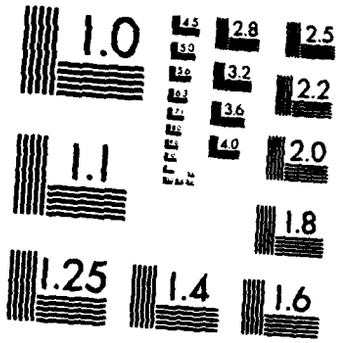

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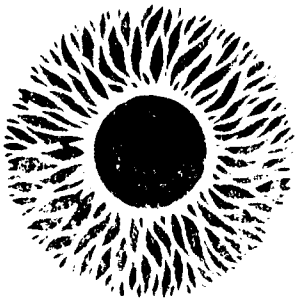

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This report concerns the effects of response modality and the relation between stimulus dimensions on subjects' ability to report one dimension of a multidimensional stimulus. Subjects were asked to report, as rapidly as possible, either the name or the ink color of colored words. The relation between the ink color and word was either congruent (Blue in blue ink), neutral (Door in blue ink), or incongruent (Blue in red ink). Responses were made either manually or vocally.

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Results are consistent with previous findings in the area of Stroop (Stroop, 1935) research. That is, responding to one of two dimensions is more difficult when the relation between dimensions is incongruent than when the relation between dimensions is congruent or neutral. But in addition, results show that no interference from an incongruent, ink-color dimension results when subjects respond vocally to the word dimension, whereas when subjects respond manually to this dimension, the incongruence between the colors and word produce interference. Results suggest a limitation on the usefulness of a color dimension when a word dimension requires a speeded-speech response.

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The Effects of Response Modality on Interference Between Stimulus Dimensions

by

V. Grayson Cuqlock and Kathryn A. Bloem

Abstract

This report concerns the effects of response modality and the relation between stimulus dimensions on subjects' ability to report one dimension of a multidimensional stimulus. Subjects were asked to report, as rapidly as possible, either the name or the ink color of colored words. The relation between the ink color and word was either congruent (Blue in blue ink), neutral (Door in blue ink), or incongruent (Blue in red ink). Responses were made either manually or vocally.

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The Effects of Response Modality on Interference Between Stimulus Dimensions.

V. Grayson Cuqlock and Kathryn A. Bloem

In an effort to increase the amount of information conveyed by one element on a display, many designers routinely used two or more physical dimensions of one element to provide different types of information. For instance, the color of a word can be used as a code, perhaps indicating the status of some equipment, while the word itself can be used to identify the equipment. The present report will discuss an experiment which illustrates when the use of a color code as a redundant dimension should be avoided.

Background

The basis for this experiment was a need to determine how the type of relation between stimulus dimensions differentially affects reaction times for speech and manual responses. Previous research has shown that speech responses are faster than manual responses if the ink and word dimensions of a colored word are dissimilar (Simon and Sudalaimuthu, 1979). Further, several other studies have offered converging evidence that the use of one of two dimensions, word or ink color, is affected by the congruence, the degree of semantic agreement, between the dimensions (Dunbar and MacLeod, 1984; Virzi and Egeth, 1985).

For instance, the typical finding of research using the Stroop, Color-Word Interference Test (Stoop, 1935) is that reaction times for naming the ink color of words that are color

names are longer than reaction times for naming the ink color of words that are not color names (Wheeler, 1977; Williams, 1977). Christ (1975; 1983) has cited many studies that indicate that the usefulness of the color dimension in providing information depends on its relation to the non-color dimension. In light of the above results, several results appear likely under various combinations of dimensional relations and response types.

Before stating the experimental rationale we must make explicit the definition of incongruent relations. We define incongruent relations as those relations between dimensions of a stimulus that result when the dimensions represent two different examples from the same semantic category. For instance, consider the catagory of color; both the color blue and the name "blue" are from the same semantic catagory (colors) and are both examples of the same specific color; these are congruent relations. By contrast, the color green and the name "blue" are also from the same semantic catagory, but are not examples of the same color; blue is not green. Therefore, the word green written in blue ink represents an incongruent relation between the two stimulus dimensions, word and ink color.

By this definition, non-color (neutral) words cannot produce incongruency when printed in various colors of ink because they are from a different semantic catagory. Furthermore, words and ink colors that are identical cannot result in incongruency

because they are semantically alike in specific example, even though different dimensions are represented.

Experimental Rationale

Consider as a first premise that there is a hierarchy of how words written in colors are processed. In this hierarchy, people process words before colors. (See Kahneman and Chojczyk (1983) for evidence that supports this premise.) A second premise is that interference between dimensions can be avoided when selective attention to one is required. If the processing time for that dimension is shorter than that of the irrelevant dimension, the relevant dimension can be processed and, more important, responded to before the irrelevant dimension. It is well documented that naming words is faster than naming colors (Morton and Chambers, 1973; Posner and Snyder, 1975) and that the Stroop effect is asymmetrical unless some experimental manipulation has slowed down the processing of the word dimension. For instance, Dunbar and MacLeod (1984) conducted several experiments in which they slowed the processing of the word and found that the ink color interfered with naming the word, the "Reversed Stroop effect."

A third premise is that interference can be further reduced if the compatibility between stimulus and response for the relevant dimension is more than the compatibility between stimulus and response for the irrelevant dimension. This greater compatibility enables the processing and responding to the

relevant dimension to occur more efficiently with little or no interference from the irrelevant dimension.

No interference from an incongruent, irrelevant dimension should occur, then, if the processing of the relevant dimension is higher in the hierarchy than the irrelevant dimension and if responding to that dimension is more compatible. These premises imply something else. If people have to respond quickly to the word dimension of a color-coded word and can do so easily, the information from the code may not be of any practical benefit. That is, the processing of the code information is so much slower than that of the word that the response to the word is made prior to the completion of the processing of the color. Thus color processing is completed too late to benefit responding to the word on any given trial. This report will discuss an experiment which provides support for this hypothesis.

Method

Design. A four-factor, mixed design was used to measure how reaction times are affected by: (a) the type of relation between the word and the color dimension (Type), (b) which dimension (color or word) is relevant for the response (Dimension), (c) the type of response, speech or manual, required (Modality), and (d) the ordering of the exposure to the Modality/Dimension combinations (Groups). There were four combinations of response modality and relevant dimension, one of the four was seen by each subject. The four combinations are manual-word (MW), manual-ink

(MI), speech-word (SW) and speech-ink (SI). Each group received one of the following four sequences of the four combinations: (1) MW-> MI-> SW-> SI, (2) MI-> MW-> SI-> SW, (3) SW-> SI-> MW-> MI, or (4) SI-> SW-> MI-> MW.

There were four levels of stimulus types:

1. Neutral -- The word used was neither congruent nor incongruent with the color of the ink in which it was printed (for example, the subject saw DOOR in red ink).

2. Congruent -- the word and the ink color were the same.

3. Incongruent -- relevant and irrelevant dimensions of the stimuli were both colors, but not the same color.

4. Doubly Incongruent -- the irrelevant dimension for the first colored word and the relevant dimension for the second colored word of consecutive words were identical (for instance, BLUE in green ink followed by RED in blue ink). In addition, the relevant and irrelevant dimensions of any given word were both colors, but not the same color.

Task. The task was an unpaced Stroop task. The subject saw individual words written in different colors of ink. Sometimes the words named colors (red, green, blue, or yellow) and at other times they named objects (car, front, door, or load). The subjects responded with a manual key-press or a speech response to either the color of the ink in which the word was written or the word itself for a block of 40 trials for each of the four

dimension/modality combinations, for a total of 160 trials for each subject.

If the subject saw the stimulus RED written in blue ink, the correct response would be "blue" if the relevant dimension was ink color and "red" if the relevant dimension was the word. The subject was told before each block of trials which dimension, the ink or the word itself, was relevant and which response modality, speech or manual, was required. At the end of each trial the subject was told the number of correct responses out of forty and the average of the reaction times.

The words were displayed for 2 s or until the subject made a response. If the subject did not respond within the 2-s interval, the stimulus was erased and the display was blank until a response was made.

Subjects. Sixteen male and female civilian subjects from Morgan State University and Aberdeen Proving Ground in Maryland participated in the experiment (8 males and 8 females). The subjects were 18 years old or older and were without anomalous color defects. Each subject was paid $15.00 for participating and the subject with the best task performance was paid a bonus of $10.00.

Apparatus. A Timex-Sinclair 2068 microcomputer was used to generate the stimuli and record the responses for this experiment. All stimuli were displayed on a Panasonic color display monitor (model CT-1310M). Reaction times for the vocal responses were

recorded by the computer via a voice-activated relay unit connected through one of the ports of the computer.

Manual responses were made by pressing the appropriate key of the board; subjects used the same four keys for making responses in all conditions. Speech responses were recorded by the computer using the voice activated relay diagrammed in Figure 1. The gain of its amplifier and threshold level controls were adjusted to fit the talker's speech level so that reliable triggering occured as soon as possible for the word responses.

Results

Analysis

A constant of 100 milliseconds was added to the speech reaction times to adjust for the amount slower the manual RTs were than the speech reaction times; this 100 msec difference was determined during a pilot study using a separate group of twenty subjects. Without this adjustment the main effect of modality was significant; however it should be noted that with or without the adjustment the same data -- the interactions involving modality -- would be the focus of comment, not the main effect of modality.

The reaction times data did not meet the sphericity assumption required for the fixed-effects analyses of variance. Therefore, a multivariate analysis of variance, with one dependent measure, was used; see O'Brien and Kaiser (1985) for a description of the use of MANOVA for analyzing repeated measures

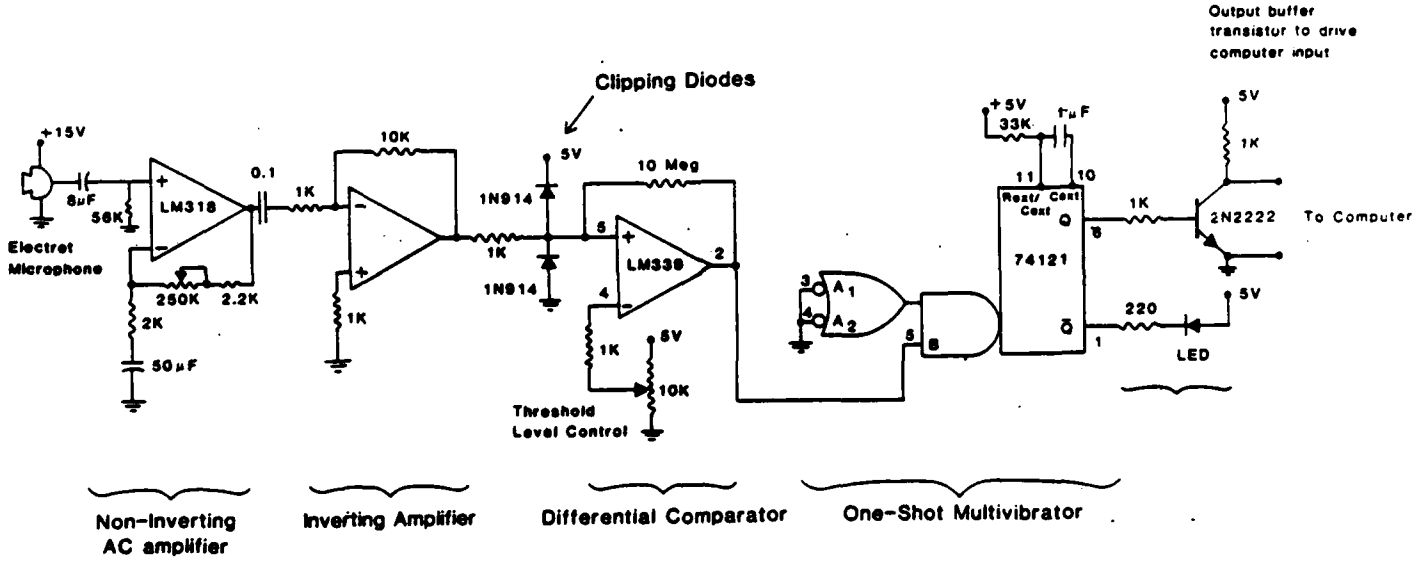

Figure 1. The voice activated relay used to measure the speech reaction times.

data. Initially this analysis included the four modality/dimension-sequences as the between-subjects factor (Groups) to test for order effects. This factor was not significant, and no interactions involving this factor were significant. Therefore, another MANOVA was run in which the data were collapsed across the groups factor.

Findings

Consistent with previous Stroop research, the results of this study show a significant effect of the type of relation between dimensions (Type) on the reaction times, $F(3,13) = 22.62$, $p<.0001$. The Tukey honestly significant difference (HSD) test was conducted to determine which differences among types were significant; the results indicated that both incongruent types produced more interference, as measured by an increase in reaction times, than the neutral and the congruent types. There was no significant difference between the congruent and neutral types, nor the two incongruent types.

Also consistent with Stroop research, the dimension main effect was significant. That is, reaction times for naming the words were shorter than reaction times for naming the ink colors, $F(1,15) = 11.56$ $p<.004$. There was a significant Dimension by Type interaction, $F(3, 13) = 4.38$ $p<.02$; although incongruent relations increased reaction times for both the ink and the word dimensions, incongruence had a much greater impact when the ink

dimension was named than when the word dimension was named. Figure 2 illustrates this interaction.

The modality main effect was not significant, but the Modality by Dimension interaction was significant, $F(1, 15) = 32.23$ $p<.0001$. As shown in Figure 3, if subjects make a manual response, it did not matter whether the relevant dimension was ink or word. But if subject made a speech response, there was a large decrease in reaction times for naming the word compared with naming the ink color.

The most noteworthy finding of this study is the significant Modality by Dimension by Type interaction, $F(3,13) = 4.62$, $p<.02$. As can be seen in Figure 4, the type of relation between dimensions of a colored word had a strong effect on reaction times if either a manual response was made for either dimension, or if the subject vocally reported the ink color. But if a speech response was required for the word dimension, the incongruence had essentially no effect on the time it took to name the word.

Accuracy

The number correct (accuracy) was only of interest to this study in determining whether there was a trade-off between speed and accuracy. The analysis of the main effects and interactions showed no evidence of this type trade-off. Subjects were accurate; the range across subjects was 90% to 97% correct for all conditions. The mean percentage correct for each condition are given in Table 1.

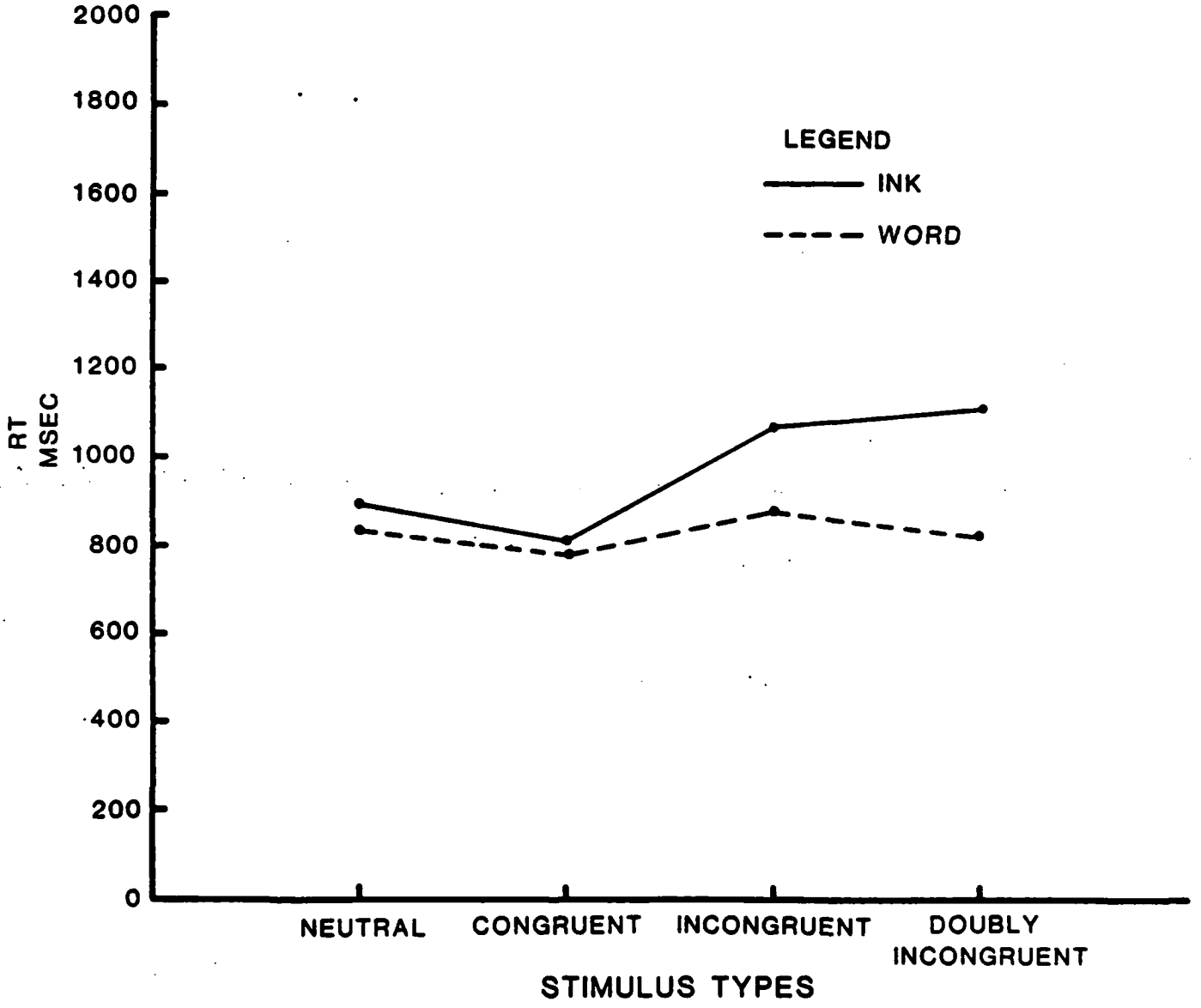

Figure 2. The mean reaction times for each of the four stimulus types for both the ink and word relevant conditions, summed across response modality.

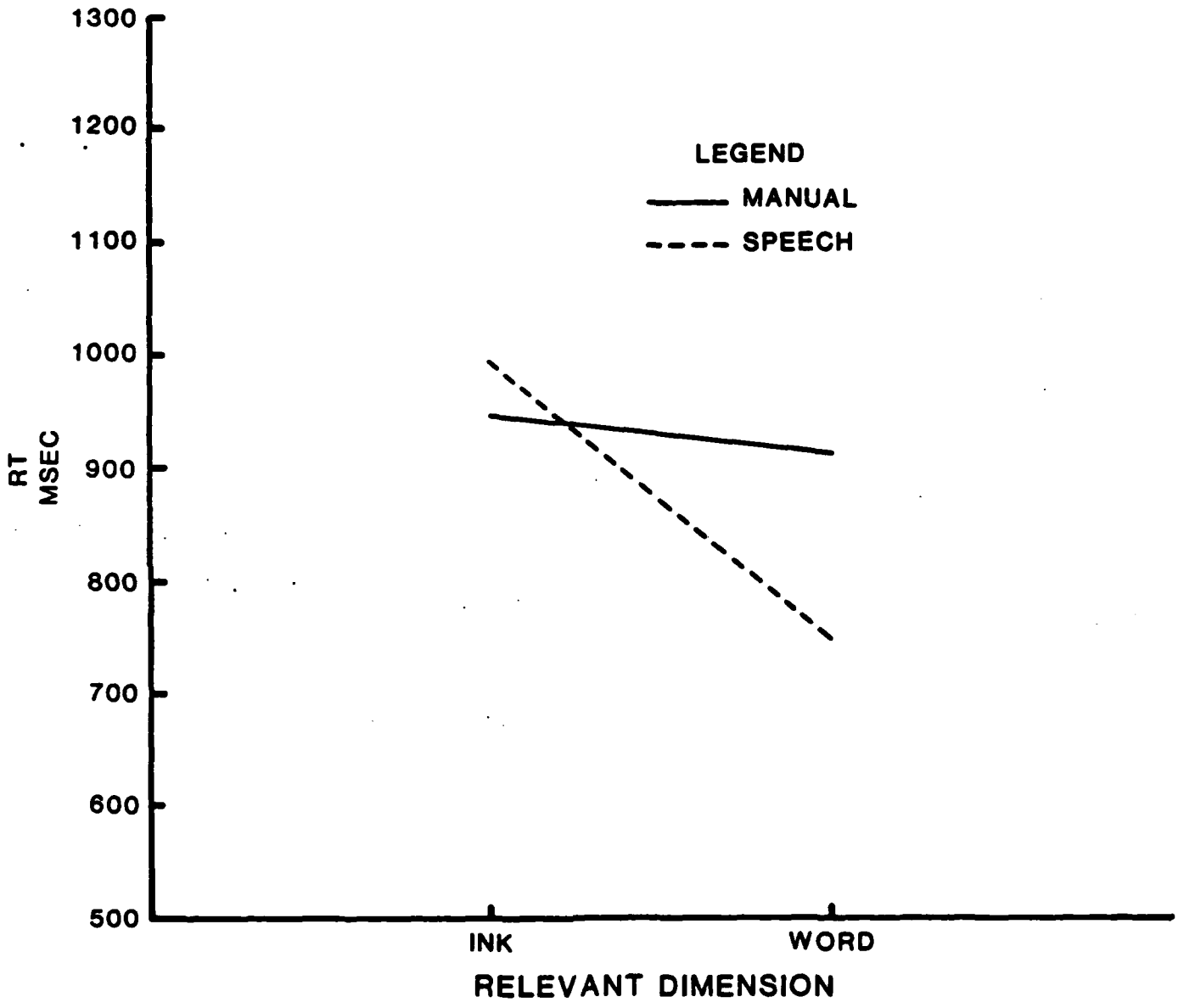

Figure 3. The mean reaction time for the ink and for the word relevant dimensions, shown separately for speech and for manual responses.

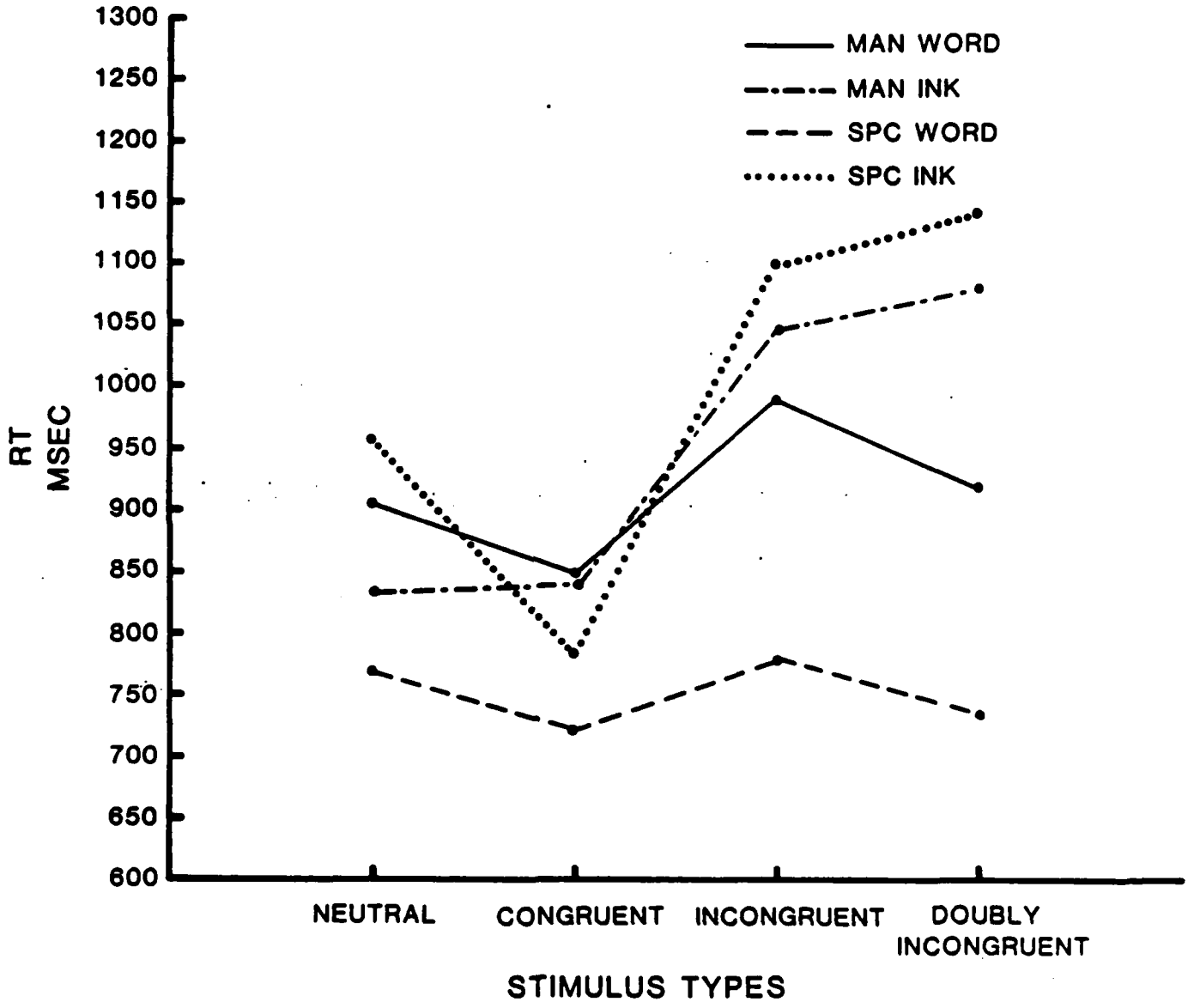

Figure 4. The mean reaction times for the four stimulus types, shown separately for the four dimension/modality combinations -- manual word, manual ink, speech word, and speech ink.

Table 1

Mean Percent Correct for each Stimulus Type, Dimension and Modality

	Speech		Manual	
	Word	Ink	Word	Ink
Neutral	39.75	39.25	38.75	39.06
Congruent	40.0	40.00	39.5	39.25
Incongruent	39.88	37.5	39.13	38.0
Doubly Incongruent	39.81	38.19	39.25	38.81

Discussion

The results of this study suggest that, when processing color-coded words, the effects of the processing of the irrelevant dimension affects performance only if the normal processing time of the relevant dimension is slower than that of the irrelevant dimension. For example, the impact of incongruent relations was much stronger when the ink (a more slowly processed dimension than word) was relevant than when the word was the relevant dimension. Likewise, if task demands change the processing time of the relevant dimension so that it becomes slower than the processing time of the irrelevant dimension (such as when a manual response is required for a word) then, too, the more dramatic effects of

the irrelevant dimension will result. The results of this study are consistent with this model.

The usual effect of the type of relation between dimensions was also found in this study. Namely, reaction times were longer when dimensions were incongruent than when the dimensions were the same or when there was no relation between the dimensions.

The main effect of modality, adjusted for the difference between the time to respond between the speech and manual devices, was insignificant, indicating that, overall, manual responses did not take significantly longer than the speech responses. On the other hand, when subjects were required to name the word, the opportunity to make a speech response greatly decreased reaction times compared to the reaction times for manual responses, as indicated by the significant Modality by Dimension interaction. This result suggests that the word dimension can be reported more efficienty by a speech rather than a manual response.

Last, the Modality by Dimension by Type interaction was significant. An examination of Figure 4 will reveal that if subjects made a speech response to name words there was no difference among the types of stimuli. This suggests that the rate of processing the word dimension is so fast that irrelevant dimension cannot have its impact before the subject responds. Apparently, for all the other three conditions, by contrast, some experimental manipulation has increased the processing time of the relevant dimension. Specifically, if transforming the relevant

dimension from a verbal code to the appropriate manual-key response is needed, as in the manual word and manual ink conditions, the effect of incongruent relations occurs. Likewise, transforming the relevant dimension from the physical representation of the color to the verbal name for that color, the speech-ink condition, also produces an increase in the time to respond to the relevant dimension. It is only when the response to a relevant dimension can be made "uninhibited" by these type transformations that no impact of the irrelevant dimension was seen. Such is the case in the Speech-Word condition.

With regard to accuracy scores, as mentioned before, the significance of the effect found indicates only that subjects' performance decreased directly in both reaction time and accuracy. Because there was no evidence of a trade-off between speed and accuracy, the reaction time results can stand unmodified.

In sum, the findings of this study indicate that the amount of interference that will result between incongruent dimensions depends on both how much the irrelevant dimension affects the processing time of the relevant dimension and the response modality used. For speech responses to words, incongruency has practically no effect on reaction times, but for speech responses to ink color, latencies to incongruent-dimension stimuli were longer than those to neutral and congruent stimuli. Manual reaction times for both word and ink color-relevant dimensions were longer for incongruent than for congruent and neutral.

The practical message of these results for the use of color-coded words is that there may be no benefit to using the color dimension of color-coded words if subjects must respond quickly to the word dimension by speech. If a color of a word is intended as a redundant code but a speedy response to the word is required, then the redundancy of the code may be useless because the word is processed and responded to before the color code can be processed. Therefore, the code information cannot serve its redundant purpose.

Notes

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Request for reprints should be sent to Director, U.S. Army Laboratory Command, Human Engineering Laboratory, Attention: SLCHE-BR (V. Grayson Cuqlock), Aberdeen Proving Ground, MD 21005-5001.

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